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MEMORANDUM REPORT ARBRL-MR-03254

A THEORETICAL INVESTIGATION OF THE FEASIBILITY OF A TWO-MODULE CHARGE IN A DUAL-CHAMBER, 155MM HOWITZER

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April 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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This report documents a theoretical study commissioned by the Office of the Project Manager, Cannon Artillery Weapons Systems to investigate the feasibility of obtaining the ballistics required for the 155-mm howitzer using a zoned, modular-charge configuration with two distinct propellant increment types when coupled with a dual-chamber volume capability. Specifically, lumped-parameter, interior-ballistic calculations were carried out for modules employing an M31-type, slotted-stick propellant in the upper

zones and M1 granular propellant in the lower zones, all packaged in combustible cases. Of the two chamber sizes, the larger was varied from 18800 to 26200 cm^3 (1150 to 1600 $in.^3$), and the smaller from 6600 to 13100 cm^3 (400 to 800 $in.^3$). The cannon length was increased with the chamber volume. Further constraints were applied regarding minimum and maximum peak pressures and the manner in which the charges would be used with the chambers. The calculations demonstrated that the upper-zone ballistics, velocities from 509 to 826 m/s (1670 to 2710 f/s), could be achieved using integral numbers of a single module for several of the large chamber sizes, depending on the tolerance allowed about the required velocities. Similarly, the lower-zone velocities from 280 to 354 m/s (920 to 1160 f/s) could be obtained with an integral number of a second increment type, but this solution was unsatisfactory in that a large number of small increments would be required. With the relaxation of one of the original, noncritical constraints, specifically, the requirement that the low-zone modules be fired exclusively in the small chamber and the high-zone modules be fired exclusively in the large chamber, the authors developed an alternative approach, the solutions of which satisfy the ballistic requirements and at the same time appear practicable from basic charge-design considerations.

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I. INTRODUCTION

Zoned artillery charges are employed to deliver a range of muzzle velocities, which, when coupled with the allowable variation of projectile launch angle, provide the range coverage desired by the artilleryman. Current practice in the artillery is to "cut" the charge by stripping the unnecessary upper-zone bagged increments away from the charge package so as to arrive at the desired charge weight. This procedure is obviously wasteful of the propellant that is not fired. Further, such current charges, being composed of nonrigid bags of propellant tied together, do not lend themselves easily to automated loading, a prime requirement of new howitzer systems. Programs are now underway to change these procedures through the development of charges, composed of a small number of rigid module types, that are built up rather than torn down. A photograph of one such "modular charge" system,[1] currently under development for the 155-mm howitzer, along with an in-service bagged charge, the M4A2, is shown in Figure 1. An even more attractive concept is that of a "universal-increment" charge, in which all of the individual

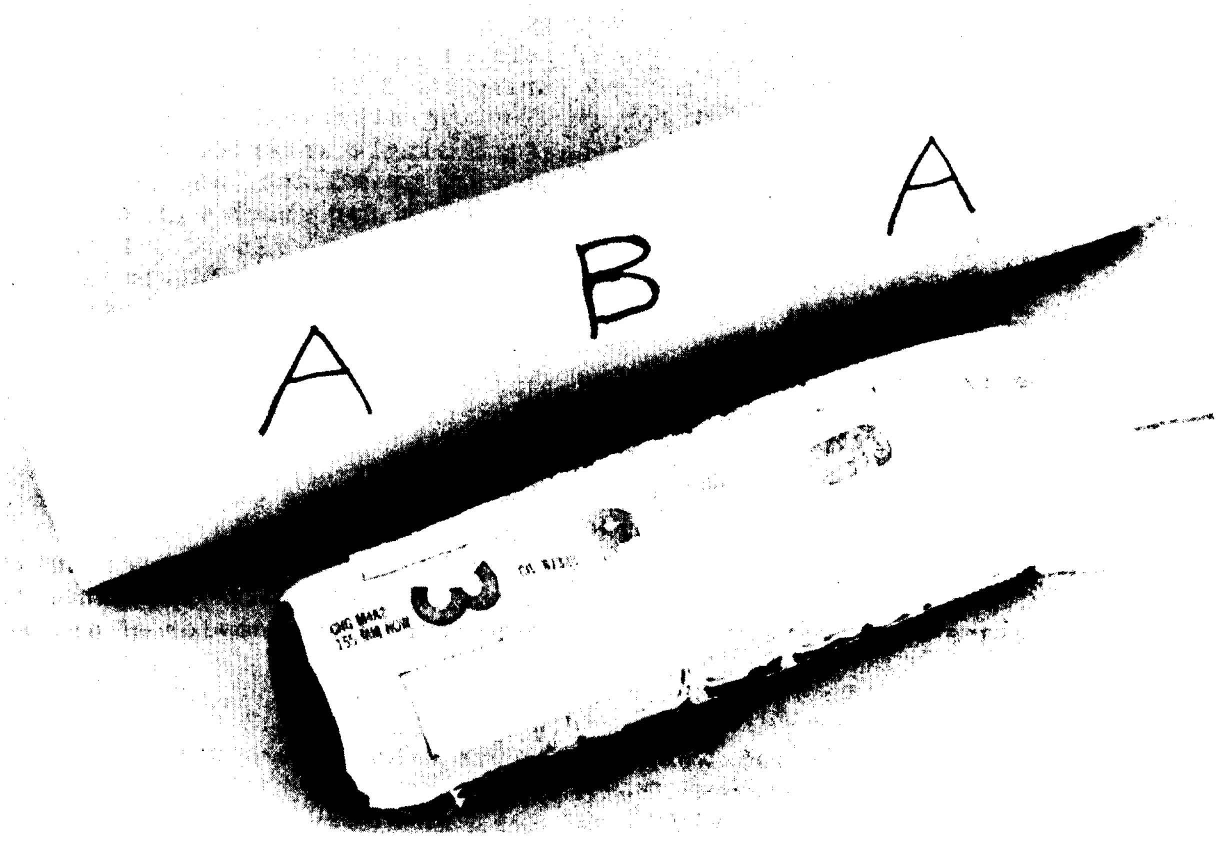

Figure 1. 155-mm, XM216, Modular Charge and 155-mm, M4A2 Charge

[1]J.A. Lannon, S. Westley and R. Garufi, "Rigid Propelling Charges for Artillery," Proceedings of Second ARRADCOM Technical Conference, 28-30 July 1982 (not yet released).

increments used to build a charge are identical. Some studies[2] have demonstrated that while this concept is attractive, restrictions imposed on the design by various system tolerances, such as peak pressure, make it impracticable. For example, this design is characterized by the need for many small, lightweight increments at the lower zones. In the course of examining these solutions, the question arose whether a variable chamber volume capability of the howitzer would render such a universal-increment or even a two-module approach feasible. This study addresses one aspect of that question.

At the request of the Office of the Project Manager, Cannon Artillery Weapons Systems (PM/CAWS), a theoretical study was carried out to determine the feasibility of a two-module charge system when fired from a 155-mm howitzer with a dual-chamber capability. The study was conducted using IBHVG,[3] a lumped-parameter, interior-ballistics program in use at the Ballistic Research Laboratory (BRL). The model assumes instantaneous (or at least preprogrammed), uniform ignition of the propellant bed, followed by a spacewise-averaged thermodynamic treatment of what is assumed to be a well-stirred mixture of propellant gas and particles. A simplified description of the pressure gradient is superimposed on this solution only for purposes of calculating the instantaneous breech pressure and the force on the projectile base. While incapable of treating igniter-related problems or the details of other hydrodynamic phenomena occurring during the interior-ballistic cycle, this code is particularly useful for performing classical charge-design studies. IBHVG has the capability to perform single interior-ballistic-trajectory calculations, given input data for gun, propellant, and projectile characteristics, and also parametric calculations, for which a given input datum is varied automatically over a user-selected range. In addition, the code will also seek to determine a propellant web or charge weight to yield a desired peak chamber pressure, or to determine a chamber volume needed to yield a desired muzzle velocity, given all the other interior-ballistic parameters. For ease of discussion, the calculations are described in the following as a series of discrete tasks, and are presented for the most part in the order that they were requested by PM/CAWS.

At the outset, some comments are in order regarding the uses of interior-ballistic calculations, particularly the ones presented here. The results obtained in any study such as this are greatly dependent on the particular code and input data employed for the simulations. Of particular relevance to this study, we are only now beginning to understand the behavior of stick-

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[2]S.I. Einstein, Large Caliber Weapon Systems Laboratory, USA ARRADCOM, private communication.

[3]R.W. Deas and F.R. Lynn, Ballistic Research Laboratory, USA ARRADCOM (report in preparation).

propellant combustion,[4,5] one manifestation of this phenomenon being that lumped-parameter calculated velocities are generally considerably lower than those realizable in the gun at a given peak pressure. Studies[6] are underway, based on intuitive physical reasoning and some experimental evidence, to modify the code, particularly in the energy partition and the pressure gradient, which may correct this deficiency. But for the present it is important to bear in mind, especially for these propellants, that the calculations are not intended to design a gun chamber or the web of a propellant grain for a charge. Such a design can only be realized through coupled theoretical studies and experimental validation programs.

II. INTERIOR-BALLISTIC CALCULATIONS

A. Task A: Baseline Two-Module, Dual-Chamber Study

Objective. The goal of this original portion of the study was to investigate the feasibility of a five-zone, two-module-type charge system for a dual-chamber, 155-mm howitzer, examined under the following constraints:

a. Gun Parameters:

Large chamber:	Volume cm^3	Volume $in.^3$	Travel m	Travel in.
	18800	1150	5.08	200
	19700-22900	1200-1400	5.97	235
	23800-26200	1450-1600	6.88	271

Small chamber:	Volume cm^3	Volume $in.^3$	Travel m	Travel in.
	6600-13100	400-800	5.97	235

b. Propellants: Zones 1-2 Unspecified
Combustible case

Zones 3-5 M31-type, slotted stick
Combustible case

c. Projectile: M549A1, 43.08 kg (95 lb)

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[4] F.W. Robbins and A.W. Horst, "A Simple Theoretical Analysis and Experimental Investigation of Burning Processes for Stick Propellant," Proceedings of 18th JANNAF Combustion Meeting, CPIA Publication 347, Vol. II, pp. 25-34, October 1981.

[5] F.W. Robbins, "Continued Study of Stick Propellant Combustion Processes," Proceedings of 19th JANNAF Combustion Meeting (CPIA Publication, not yet released).

[6] F.W. Robbins, Ballistic Research Laboratory, USA ARRADCOM, private communication.

d. Velocities: [at 21 °C (70 °F)]

Zone	m/s	f/s
1	280	920
2	354	1160
3	509	1670
4	684	2245
5	826	2710

e. Pressures: [at 21 °C (70 °F)]

Zone	Maximum		Minimum	
	Mpa	kpsi	Mpa	kpsi
1			69	10.0
4	228	33.0		
5	328	47.5		

Additionally, the charge was to be constructed such that Zones 1 and 2, made of one module type, were to be fired in the smaller chamber, and Zones 3, 4, and 5, made from the second module type, were to be fired from the larger chamber. It was the intent, due primarily to loading considerations, that the upper zone module not be fired in the smaller chamber nor the lower zone module fired in the larger chamber. This desired solution is shown schematically in Figure 2. The velocities are those which would yield the appropriate range overlap between adjacent zones, and are not necessarily unique. The minimum pressure for the Zone-1 charge is intended to lessen the probability of projectile stickers at that zone. The pressure limit on the Zone-4 charge is to accommodate the stringent acceleration limitations of the M712, Cannon Launched Guided Projectile, and to some extent, the pressure tolerance of the M483A1 family of projectiles. The peak pressure for the Zone-5 Charge is imposed by the operating limit of the M549A1 Projectile.

Procedure. The following procedure was employed to complete this phase of the study:

a. For each chamber volume 18800-26200 cm^3 (1150-1600 $in.^3$) and appropriate tube length, the volume was varied in increments of 820 cm^3 (50 $in.^3$) to determine the web and charge weight required to yield 826 m/s (2710 f/s) at 328 Mpa (47.5 kpsi) for Zone 5.

b. The velocities and pressures at quarters and thirds of these charge weights were determined in the same chambers to assess suitability for Zones 3 and 4. Due to handling, loading, and performance considerations discussed more fully below, four was chosen as a reasonable maximum number of increments into which the top-zone charge could be divided.

c. For each tube length 5.97 and 6.88 m (235 and 271 in.), and for each chamber volume 6600-13100 cm^3 (400-800 $in.^3$), the volume was varied by increments of 820 cm^3 (50 $in.^3$) to determine the web and charge weight needed to produce the Zone-1 velocity of 280 m/s (920 f/s) at a pressure in excess of 69 MPa (10 kpsi). Single-perforation M1 propellant, with webs in the vicinity of 0.41 mm (0.016 in.), was selected based on past experience with low-zone propelling charges.

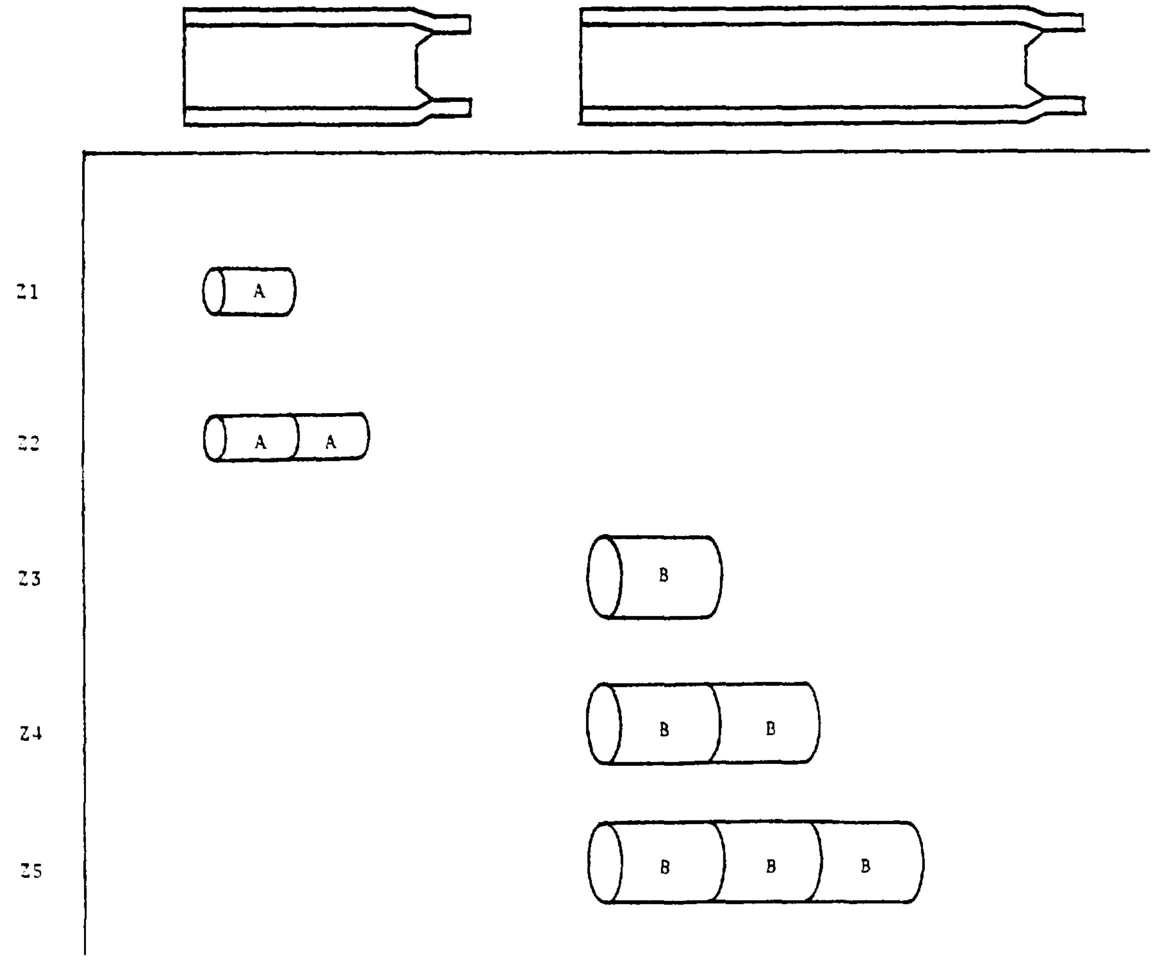

Figure 2. Requested Two-Module, Dual-Chamber Solution

d. For each of the solutions of paragraph c, velocities and pressures for additional increments of thirds and quarters of the Zone-1 charge weight were determined in the same chamber to assess suitability for Zone 2.

For the most part, the input to the code, especially that pertaining to the thermochemical and combustion properties of the slotted-stick, M31-type propellant, was assembled from a data base[2] provided by the Large Caliber Weapon Systems Laboratory (LCWSL) as part of a LCWSL-BRL cooperative study comparing several modular-charge zoning solutions. The length of the propellant sticks, which will have an insignificant effect on the calculations, was arbitrarily selected to be 25.4 cm, and the web and perforation diameter were taken to be equal. The thermochemical and combustion parameters for the combustible case were those used in the past at BRL for the felted-nitrocellulose, centercore-igniter tube for the 155-mm, M203 Charge. The physical characteristics of the combustible case, including the admittedly low weight, were supplied by the LCWSL as part of the interior-ballistic comparison study. Standard BRL inputs were selected for the igniter

data. The bore resistance data were those independently determined for the 155-mm howitzer with instrumented projectiles.[7] The input for selected computer runs is given in the Appendix.

Results. The results from the calculations for this portion of the study are displayed in Table 1 for the upper zones and in Table 2 for the lower zones. In these and subsequent tables, the chamber volume, length of projectile travel, propellant web, charge weight or fraction of top-zone charge weight, peak breech pressure, muzzle velocity, and travel at propellant burnout are given. As an example, the summary computer output from the computations for the 22900-cm^3 (1400-$in.^3$) chamber is given in the Appendix. The authors are fully aware that the calculated webs of the propellants and charge weights vary somewhat from those determined experimentally in charge development programs. The reader is referred to our earlier comments concerning the uses of the results of interior-ballistic calculations. Some of the results in the 19700-21300 cm^3 (1200-1300 $in.^3$) chamber range imply solutions for Zones 3 and 4 with half and three-quarters the top-zone weight provided one is allowed to stray somewhat from the requirements of 509 and 684 m/s (1670 and 2245 f/s). These solutions are depicted schematically in Figure 3. The calculations for thirds of the Zone-5 weight failed to produce velocities as near the requirements for Zones 3 and 4 as did the quarters, and thus are not listed in the table.

The calculation for the 18800-cm^3 (1150-$in.^3$) chamber was attempted, but it would not produce the required top-zone velocity at a pressure of 328 MPa (47.5 kpsi), no matter what the web selected. Since the design program for the 155-mm, M203E2 Propelling Charge indicates that this velocity can be achieved at this pressure in this chamber, this phenomenon once again illustrates the current inability to model the interior-ballistic process of stick propellants adequately, as discussed earlier.

To assess the sensitivity of the results to the input data, several additional calculations were done with different but not unreasonable thermochemical and burning rate values, and they demonstrated that the charge weight may increase, along with a change in the web, by about one and one-half pounds for the top zone. The results of the Zone-3 and Zone-4 calculations change somewhat, at the expense of moving the Zone-4 velocity closer to 684 m/s (2245 f/s) and the Zone-3 velocity farther from 509 m/s (1670 f/s). However, the basic conclusions arising from the computations do not change.

The results from the Zone-1 and Zone-2 calculations are shown in Table 2. Sample calculations for the 13100-cm^3 (800-$in.^3$) chamber are given in the Appendix. A series of probe calculations demonstrated that Zone-1 velocity with M1 SP propellant in a web of the order of 0.41 mm (0.016 in.) could be attained only with peak pressure in excess of 103 MPa (15 kpsi). The results of calculations that produced velocities within 12 m/s (40 f/s) of the 354-m/s (1160-f/s), Zone-2 target are shown. For the 5.97-m (235-in.) cannon, any of

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[7] J.W. Evans, "A Technique for Measuring Engraving and Bore Frictional Forces in Large Caliber Guns," Proceedings of the 33rd Meeting of the Aeroballistic Range Association, August 1982.

Table 1. Results of Calculations for Upper Zones

CH VOL		TR		WEB			WT		PMAX		VEL		TR@BO	
cu.cm	cu.in.	m	in.	mm	in.	frac	kg	lb	MPa	kpsi	m/s	f/s	m	in.
19700	1200	5.97	235	1.73	0.068	4/4	12.19	26.88	328	47.5	825	2707	3.02	119
						3/4			202	29.3	673	2207	3.84	151
						2/4			121	17.6	512	1679	4.65	183
20500	1250	5.97	235	1.63	0.064	4/4	12.02	26.51	328	47.5	826	2710	2.49	98
						3/4			204	29.6	677	2220	3.10	122
						2/4			123	17.8	517	1697	3.76	148
21300	1300	5.97	235	1.55	0.061	4/4	11.93	26.31	328	47.5	826	2710	2.16	85
						3/4			205	29.8	678	2226	2.64	104
						2/4			123	17.9	521	1708	3.18	125
22100	1350	5.97	235	1.50	0.059	4/4	11.95	26.34	328	47.5	826	2711	1.93	76
						3/4			206	29.9	680	2232	2.39	94
						2/4			124	18.0	523	1717	2.82	111
22900	1400	5.97	235	1.45	0.057	4/4	11.94	26.33	328	47.5	825	2708	1.78	70
						3/4			207	30.0	681	2235	2.13	84
						2/4			125	18.2	525	1722	2.51	99
23800	1450	6.88	271	1.32	0.052	4/4	11.46	25.27	328	47.5	828	2716	1.42	56
						3/4			208	30.2	686	2251	1.70	67
						2/4			126	18.3	529	1737	1.93	76
24600	1500	6.88	271	1.30	0.051	4/4	11.55	25.47	328	47.5	828	2717	1.35	53
						3/4			209	30.3	687	2254	1.60	63
						2/4			127	18.4	531	1741	1.83	72
25400	1550	6.88	271	1.27	0.050	4/4	11.63	25.65	328	47.5	827	2715	1.27	50
						3/4			210	30.4	687	2255	1.50	59
						2/4			128	18.5	531	1743	1.70	67
26200	1600	6.88	271	1.24	0.049	4/4	11.70	25.80	328	47.5	827	2713	1.22	48
						3/4			210	30.4	687	2255	1.42	56
						2/4			128	18.5	532	1744	1.60	63

the chamber sizes considered can be used, with a three-pillet Zone 1 and a four-pillet Zone 2. The solution can be achieved similarly with the 6.88-m (271-in.) cannon, provided one accepts a larger divergence from the desired Zone-2 velocity. Further, approximate Zone-2 solutions can be achieved in the 6.88-m (271-in.) cannon with a four-pillet Zone 1 and a five-pillet Zone 2. These solutions are illustrated schematically in Figure 3.

Table 2. Results of Calculations for Lower Zones

CH VOL		TR		WEB			WT		PMAX		VEL		TR@BO	
cu.cm	cu.in.	m	in.	mm	in.	frac	kg	lb	MPa	kpsi	m/s	f/s	m	in.
13100	800	5.97	235	0.394	0.0155	3/3	1.99	4.38	110	16.0	280	920	0.30	12
						4/3			150	21.7	357	1170	0.33	13
		6.88	271	0.406	0.0160	3/3,4/4	2.04	4.50	110	16.0	280	920	0.33	13
						5/4			139	20.1	343	1124	0.33	13
						4/3			150	21.7	361	1185	0.33	13
12300	750	5.97	235	0.406	0.0160	3/3	1.97	4.34	110	16.0	282	925	0.33	13
						4/3			150	21.7	358	1176	0.36	14
		6.88	271	0.417	0.0164	3/3,4/4	2.05	4.51	110	16.0	280	920	0.36	14
						5/4			139	20.2	343	1124	0.36	14
						4/3			150	21.7	361	1185	0.36	14
11500	700	5.97	235	0.417	0.0164	3/3	1.93	4.26	110	16.0	282	924	0.39	15
						4/3			150	21.8	358	1175	0.38	15
		6.88	271	0.429	0.0169	3/3,4/4	1.98	4.37	110	16.0	281	921	0.41	16
						5/4			139	20.2	343	1125	0.41	16
						4/3			150	21.8	361	1186	0.41	16
10700	650	5.97	235	0.417	0.0164	3/3	1.90	4.19	110	16.0	282	924	0.38	15
						4/3			150	21.8	358	1175	0.41	16
		6.88	271	0.445	0.0175	3/3,4/4	1.96	4.31	110	16.0	281	921	0.43	17
						5/4			139	20.2	343	1126	0.43	17
						4/3			150	21.8	362	1187	0.43	17
9800	600	5.97	235	0.445	0.0175	3/3	1.86	4.11	110	16.0	281	921	0.46	18
						4/3			150	21.8	358	1173	0.46	18
		6.88	271	0.462	0.0182	3/3,4/4	1.93	4.26	110	16.0	281	921	0.51	20
						5/4			140	20.3	343	1127	0.48	19
						4/3			151	21.9	362	1188	0.48	19
9000	550	5.97	235	0.462	0.0182	3/3	1.83	4.04	110	16.0	280	920	0.51	20
						4/3			151	21.9	358	1173	0.51	20
		6.88	271	0.485	0.0191	3/3,4/4	1.91	4.21	110	16.0	281	922	0.58	23
						5/4			140	20.3	344	1128	0.56	22
						4/3			151	21.9	363	1190	0.56	22
8200	500	5.97	235	0.493	0.0194	3/3	1.81	4.00	110	16.0	281	921	0.64	25
						4/3			151	21.9	358	1175	0.58	23
		6.88	271	0.511	0.0201	3/3,4/4	1.88	4.14	110	16.0	280	919	0.69	27
						5/4			141	20.4	343	1125	0.66	26
						4/3			152	22.0	362	1187	0.64	25

Table 2. Results of Calculations for Lower Zones (Cont'd)

CH VOL		TR		WEB			WT		PMAX		VEL		TRmBO	
cu.cm	cu.in.	m	in.	mm	in.	frac	kg	lb	MPa	kpsi	m/s	f/s	m	in.
7400	450	5.97	235	0.523	0.0206	3/3	1.79	3.94	110	16.0	279	917	0.76	30
						4/3			152	22.0	357	1170	0.71	28
		6.88	271	0.551	0.0217	3/3,4/4	1.87	4.13	110	16.0	280	919	0.86	34
						5/4			141	20.4	343	1126	0.84	33
						4/3			152	22.0	362	1189	0.81	32
6600	400	5.97	235	0.584	0.0230	3/3	1.81	4.00	110	16.0	281	923	1.09	43
						4/3			152	22.1	360	1181	0.99	39
		6.88	271	0.615	0.0242	3/3,4/4	1.89	4.17	110	16.0	280	919	1.27	50
						5/4			141	20.5	344	1129	1.17	46
						4/3			152	22.1	363	1192	1.17	46

Conclusions. From the foregoing, it is clear that a two-module solution for a dual-chamber, 155-mm howitzer exists, but suffers some drawbacks. The suitability of a particular upper-zone solution depends on the latitude allowed about the desired muzzle velocities. The solution for the lower zones is far from satisfactory, however, in that several small pillets are required for even the Zone-1 charge. This physical configuration could well present problems in handling and loading in that the charge might tend to fall apart or separate in the chamber. Perhaps more importantly, however, are the ignition and flamespread characteristics of the charge. Systematic studies[8,9] of multizone artillery propelling charges, both in bagged and rigid, modular configurations, have demonstrated that all aspects of the propellant packaging, ignition, and loading need careful consideration by the charge designer, as an improper selection of design parameters can result in potentially deleterious pressure waves or solid-phase (e.g., propellant grains, packaging components, or entire charge increments) motion. Again, we caution the reader that these calculations are intended to demonstrate the feasibility (or lack of it) of a given charge design concept; they are not to be used to design a particular charge.

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[8] C.R. Ruth and T.C. Minor, "Multi-Zone Artillery Propelling Charge Studies," Proceedings of 1981 JANNAF Propulsion Meeting, CPIA Publication 340, Vol. I, pp. 55-71, May 1981.

[9] C.R. Ruth and T.C. Minor, "Multi-Zone, Modular Artillery Propelling Charge Studies," Proceedings of 1983 JANNAF Propulsion Meeting (CPIA Publication, in preparation).

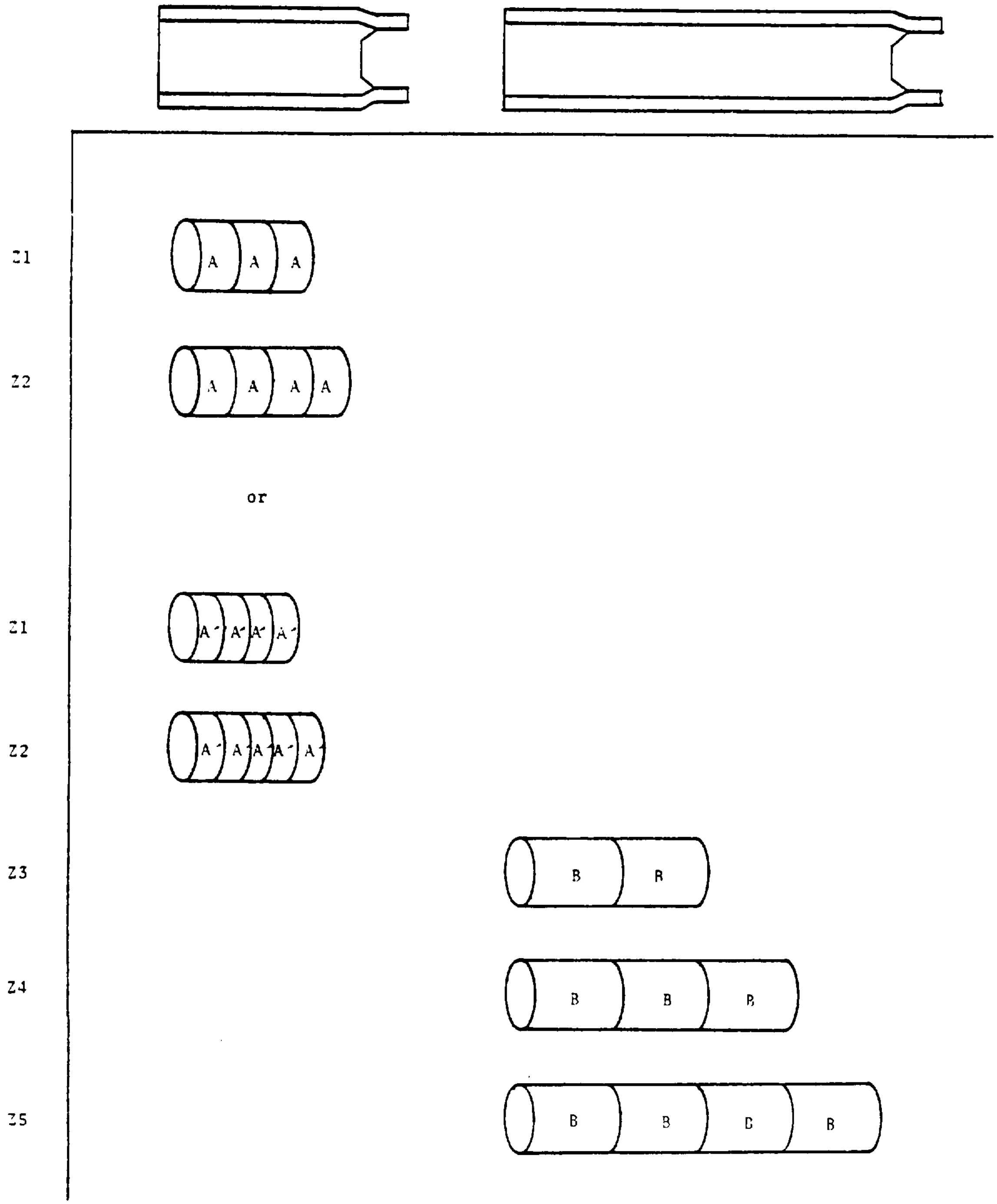

Figure 3. Calculated Two-Module, Dual-Chamber Solution

The unsatisfactory nature of the design of the lower zones leads us to propose some alternative concepts. These proposals require a relaxation of the constraint that the upper-zone modules be used only in the large chamber and the lower-zone modules be employed exclusively in the small chamber. It is clear from the previous calculations that a chamber volume can be determined which would yield Zone-2 ballistics with one-quarter of the top-zone charge weight. It is also clear that stand-alone charges can be determined for any given chamber volume. Based on these premises, these solutions follow:

a. Determine the necessary chamber volume for a Zone 2 velocity using one-quarter of the Zone 5 charge weight. This reduced chamber volume may be achieved either with a separate chamber or with a volume-reducing element used with the larger chamber. Design a stand-alone, single-increment charge to yield Zone 1 ballistics for either the large or the reduced-volume chamber. This solution is illustrated in Figure 4.

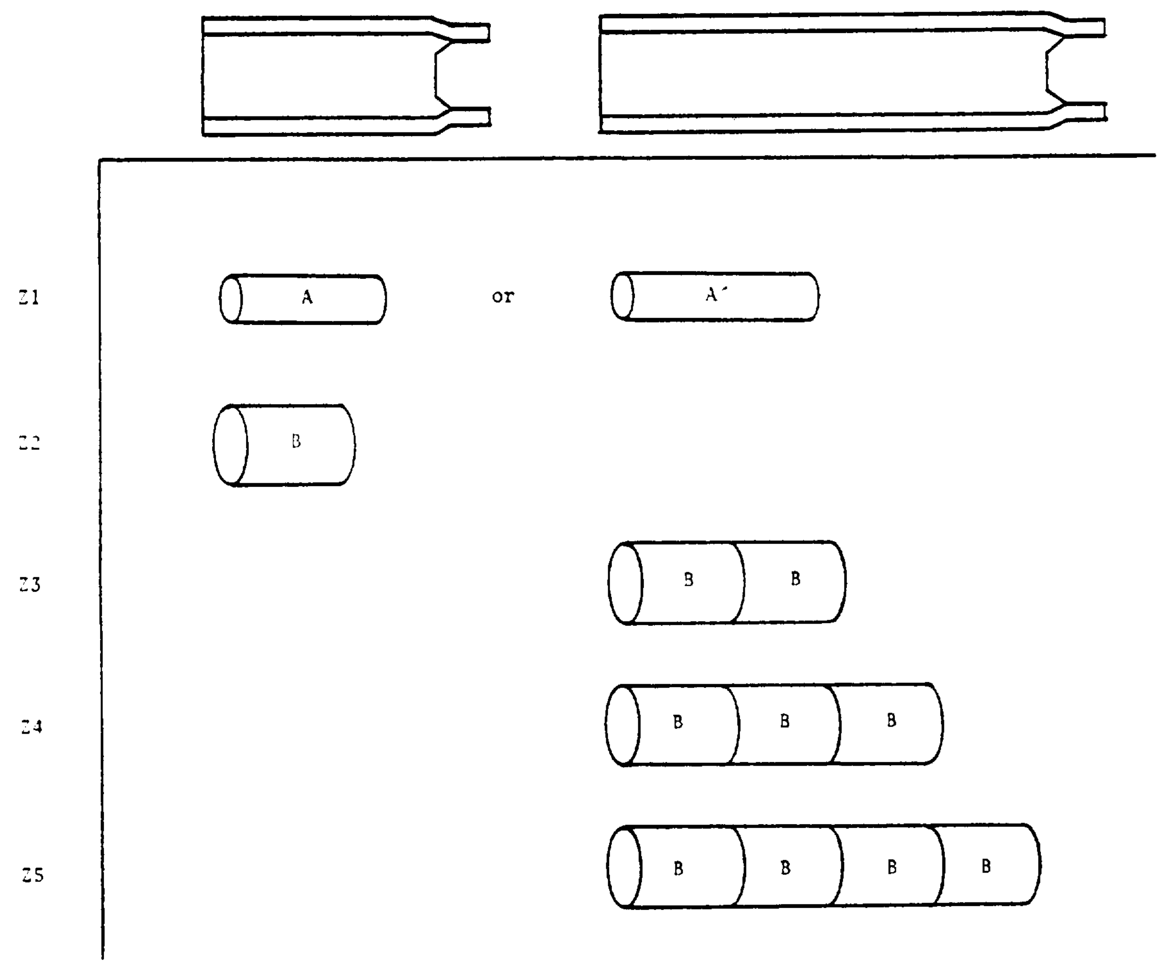

Figure 4. Proposed Two-Module, Dual-Chamber Solution, Alternative I

b. Design a single-increment Zone 1 charge for the larger chamber; then determine the smaller chamber necessary to yield Zone 2 ballistics with this same increment. The reduced chamber volume can again be achieved either with a separate chamber or with a volume-reducing element used with the larger chamber. This solution is illustrated in Figure 5.

The obvious advantage to these proposed solutions is that they do not require small pillet weights.

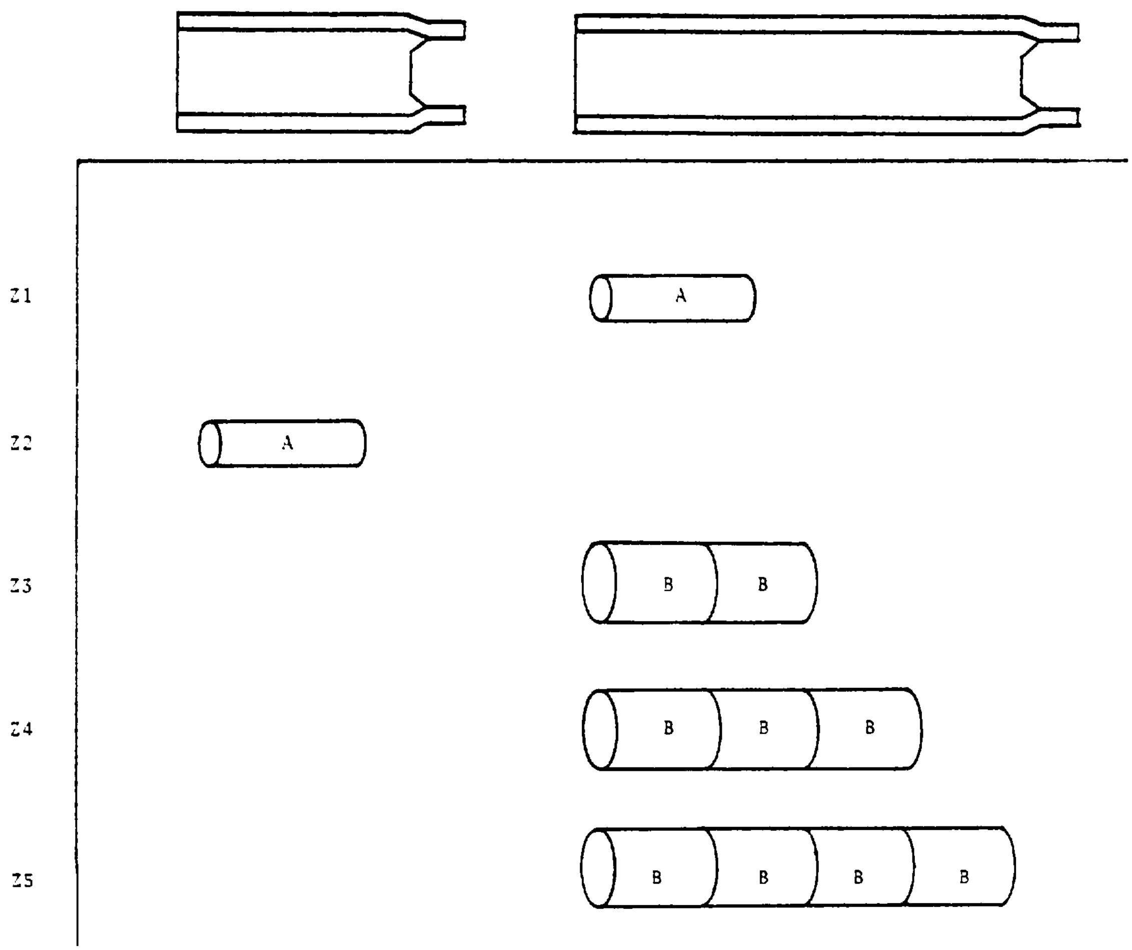

Figure 5. Proposed Two-Module, Dual-Chamber Solution, Alternative II

B. Task B: Determination of Volume of Small Chamber for Zone 2

Objective. Given the preceding proposals, one natural question asked was the size of the chamber needed to provide the Zone-2 ballistics with a quarter of the top-zone weight. Further, the potential for projectile stickers in a cannon employing only this quantity of propellant weight requires investigation. The 22900-cm^3 (1400-$in.^3$) chamber appears to be the primary candidate for any new larger-chamber artillery weapon system to be developed. Accordingly, the charge solution computed for this chamber size was selected for use in the determination of the reduced chamber size for Zone 2.

Procedure and Results. Using the charge parameters for one-quarter of the top-zone weight for the charge system determined for the 22900-cm^3 (1400-$in.^3$) chamber, IBHVG was run with a variation in chamber size to arrive at that volume which would yield approximately 354 m/s (1160 f/s). The output from that run is given in the Appendix. The run showed that with this charge increment, the Zone-2 velocity could be obtained with a chamber of 14300 cm^3 (874 $in.^3$). The peak pressure is about 85 MPa (12.4 kpsi), which should place the performance outside the regime where projectile stickers would be of concern.

C. Task C: Assessment of Compatibility with Current Howitzers, M198 and M109A2/A3

Objective. Since currently fielded howitzers will be in use into the foreseeable future, it seems reasonable to assess the suitability of a particular solution determined for the larger chamber gun when applied to the smaller chamber of these in-service howitzers. Again, due to its relevance to the anticipated developmental systems, the particular solution selected for this portion of the study was that developed for the 22900-cm^3 (1400-$in.^3$) chamber.

Procedure and Results. Interior-ballistic trajectories were recomputed using the charges determined for the 22900-cm^3 (1400-$in.^3$) chamber, with all the input data unchanged except the chamber volume and cannon length. The results of this set of calculations, including that for Zone 2, are given in Table 3. As expected, the computed pressure increased for the upper zones and decreased for Zone 2. While the Zone-2 pressure might be acceptable, that determined for the top zone is probably beyond currently tolerable levels. The Zone-4 pressure also exceeds the 228-MPa (33-kpsi) limit originally established for the study. Furthermore, an assessment would be required as to the suitability of the projectile ranges arising from the computed velocities. A calculation for the Zone-1 charge was not performed, but two solutions would exist, depending on whether the stand-alone charge were designed for the smaller or larger of the dual-chamber configurations in the 22900-cm^3 (1400-$in.^3$) system.

Table 3. Results of Calculations for Current Howitzers

CH VOL		TR		WEB		WT			PMAX		VEL		TR990	
cu.cm	cu.in.	m	in.	mm	in.	frac	kg	lb	MPa	kpsi	m/s	f/s	m	in.
18800	1150	5.08	200	1.45	0.057	4/4	11.94	26.33	418	60.6	850	2789	1.70	67
						3/4			249	36.1	693	2275	2.18	86
						2/4			143	20.7	529	1736	2.69	106
						1/4			75	10.9	336	1104	2.92	115

D. Task D: Two-Module, Dual-Chamber Study for Reduced Peak Pressure

Objective. The foregoing top-zone calculations were all conducted for a peak pressure of 328 MPa (47.5 kpsi), a pressure reflecting the maximum acceptable average for the M549A1 Projectile at 21 °C (70 °F). The 155-mm, M483A1 Projectile, now in the inventory in large numbers, will not tolerate pressures at elevated temperatures that are implied by this ambient pressure. We were lastly tasked to determine the possibility of designing a two-module charge for a dual-chamber howitzer operating at a pressure of only 262 MPa (38 kpsi). Such a pressure at 21 °C (70 °F) with the M549A1 Projectile should permit use of the charge with the M483A1 even at elevated temperatures. For the reasons discussed previously, the large chamber was taken to have a volume of 22900 cm^3 (1400 $in.^3$).

Procedure and Results. A series of probe calculations similar to those of Task A was conducted with IBHVG at a peak pressure of 262 MPa, with the result that a Zone-5 velocity level of 826 m/s (2710 f/s) could not be achieved, no matter what the web of the propellant or the weight of the charge. In an attempt to find some solution in this pressure range, the calculations were repeated at a maximum pressure of 276 MPa (40 kpsi). Here again, the computations indicated that the desired performance could not be attained, with a maximum velocity of only 803 m/s (2636 f/s) achievable. However, since it is well known from past experience with these propellants that the predicted muzzle velocities may be on the order of 30 m/s (100 f/s) lower, at these pressures, than those realizable in the gun, it is entirely possible that a top-zone solution exists. Given such a possibility, calculations were carried out for quarters of the top-zone charge weight as before in the hope that the velocities would fall near the desired performance levels. The results of the simulations are shown in Table 4, and the summary computer output is given in the Appendix. The calculated velocities for one-half and three-quarters of the top-zone charge weight are less than those required for the Zone-3 and Zone-4 levels, respectively, but may be close enough to the target values that there is a reasonably high probability of achieving the desired performance experimentally.

Table 4. Results of Calculations for 22900-cu.-cm Main Chamber, 276-MPa Top-Zone Peak Pressure

CH VOL		TR		WEB			WT		PMAX		VEL		TRGBO	
cu.cm	cu.in.	m	in.	mm	in.	frac	kg	lb	MPa	kpsi	m/s	f/s	m	in.
22900	1400	5.97	235	1.99	0.0785	4/4	13.49	29.75	276	40.0	803	2636	4.60	181
						3/4			176	25.5	653	2143	5.66	223
						2/4			109	15.8	497	1631	>5.97	>235
22900	1400	5.97	235	1.99	0.0785	1/4			60	8.7	310	1016	>5.97	>235
19700	1202								65	9.4	314	1030	>5.97	>235
9800	601								93	13.5	320	1050	>5.97	>235
4900	301								197	28.5	332	1089	>5.97	>235
2500	150	* * * CALCULATION ABORTED * * *												

The last five lines of Table 4, and the last inclusions in the Appendix, document our attempt to determine the size of the smaller chamber needed to yield Zone-2 ballistics with one-quarter of the top-zone weight. As noted, the attempt was not successful, due to the lack of burnout of the propelling charge in the gun. An indication that this would be a problem can be seen in the computation for one-half the top-zone weight, where the charge also did not completely burn within the gun. Again, the calculated velocities are probably lower than those which could be obtained in a gun, but probably not to the 30-m/s (100-f/s) extent noted for charges operating at the much higher pressure level. Thus, in this case, there is only a marginal possibility that such an appropriately sized chamber exists.

III. CONCLUSIONS

We have performed a theoretical study using a lumped-parameter interior-ballistics code to examine the feasibility of using a two-module type, zoned artillery charge in a 155-mm howitzer with a dual-chamber capability. Although great advances are being made in our understanding of stick-propellant combustion, our computational ability with these propellants is still, as of this date, not at a stage where exact performance parameters can be calculated from uncompromised data bases. Nevertheless, some valid conclusions can be reached from the computations of this study. Specifically, the findings were that:

a. A solution in which the lower zones can be fired only in the smaller chamber and the upper zones in the larger chamber is unsatisfactory in that a large number of small increments that would be required for the lower zones, with accompanying logistical and ignition problems.

b. Relaxation of one of the original concept constraints to allow use of either of the two module types in either chamber yields a set of simple solutions, illustrated in Figures 4 and 5.

c. The solutions described in paragraph b would not be acceptable in the current M198 and M109A2/A3 Howitzers due to high pressures at Zones 4 and 5.

Finally, it is important to stress once again that the exact results reflect the input data used for the code. Another input data base, or interior-ballistic code, would undoubtedly produce slightly different results. It is not expected, however, that they would alter the basic conclusions of this study. The calculations are not intended to be used to design a chamber of a gun or the web of a propellant without experimental verification. Rather, they are to be used as indicators of the potential of the charge design options addressed in this study.

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APPENDIX A

SAMPLE INTERIOR-BALLISTIC CALCULATIONS

LIST OF SAMPLE CALCULATIONS

1400-CU-IN CHAM; 47.5-KPSI TOP ZONE

GUN TYPE: DSWS 1400	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 1400.00 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 6.0
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	26.331
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	6.15	14.62	1.60	3.55	8.95
BR PRES [KPSI]	47.52	8.55	5.06	23.15	32.86
MN PRES [KPSI]	45.63	8.26	4.92	22.32	31.59
BS PRES [KPSI]	41.87	7.69	4.62	20.66	29.03
MEAN TEMP [K]	2320.	1514.	2575.	2455.	2024.
TRAVEL [IN]	18.8	235.0	.2	2.0	69.8
VEL [FPS]	999.	2708.	25.	179.	1971.
ACCEL [G'S]	12370.	1888.	966.	5453.	8402.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.137	1.000	1.000
FR BRNT PROP 3	.595	1.000	.034	.179	1.000

1400-CU-IN CHAM; 3/4 OF 47.5-KPSI TOP-ZONE WT

GUN TYPE: DSWS 1400	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 1400.00 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 6.0
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	19.748
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	-------	-------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	7.85	18.27	1.95	4.65	12.05
BR PRES [KPSI]	30.00	6.50	3.56	16.47	19.76
MN PRES [KPSI]	29.10	6.34	3.50	16.04	19.19
BS PRES [KPSI]	27.30	6.02	3.37	15.17	18.04
MEAN TEMP [K]	2324.	1574.	2580.	2433.	2007.
TRAVEL [IN]	19.2	235.0	.2	2.2	84.1
VEL [FPS]	805.	2235.	20.	150.	1700.
ACCEL [G'S]	7800.	1379.	547.	3753.	4979.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.127	1.000	1.000
FR BRNT PROP 3	.566	1.000	.034	.190	1.000

1400-CU-IN CHAM; 1/2 OF 47.5-KPSI TOP-ZONE WT

GUN TYPE: DSWS 1400
CHAMBER VOLUME: 1400.00 CU IN
GROOVE DIAMETER: 6.200 IN
GROOVE/LAND RATIO: 1.660
TWIST: ONE TURN IN 20.0 CALIBERS
PRESSURE GRADIENT: LAGRANGIAN
PROJECTILE: M549A1

BORE LENGTH: 235.0 IN
TIME STEP: .100 MS
LAND DIAMETER: 6.100 IN
BORE AREA: 29.828 SQ IN
EXPANSION RATIO: 6.0
EROSIVE COEFF: 0.0000000
PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	13.166
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	10.45	24.19	2.50	6.40	17.05
BR PRES [KPSI]	18.15	4.35	2.47	11.14	10.84
MN PRES [KPSI]	17.79	4.28	2.46	10.96	10.64
BS PRES [KPSI]	17.07	4.16	2.42	10.60	10.23
MEAN TEMP [K]	2321.	1605.	2582.	2401.	1965.
TRAVEL [IN]	17.8	235.0	.2	2.0	99.3
VEL [FPS]	599.	1722.	15.	102.	1382.
ACCEL [G'S]	4586.	807.	212.	2286.	2560.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.124	1.000	1.000
FR BRNT PROP 3	.544	1.000	.036	.206	1.000

800-CU-IN CHAM; 235-IN TRAVEL; 16.0-KPSI ZONE 1

GUN TYPE: DSWS 800	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 800.00 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 9.8
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M1, SP
WEIGHT [LB]	.188	.350	4.378
IMPETUS [FT-LB/LB]	346180.	180000.	305000.
FLAME TEMP [K]	3034.	1553.	2417.
ALPHA	.8650	1.0000	.7140
BETA	.000826	.001500	.001600
GAMMA	1.235	1.250	1.259
COVOL [CU IN/LB]	29.680	30.000	30.570
DENS [LB/CU IN]	.06033	.03400	.05670
GRAIN TYPE	1-PERF	1-PERF	1-PERF
GRAIN LEN [IN]	.0040	15.0000	.2093
GRAIN DIAM [IN]	.0180	6.1750	.0465
PERF DIAM [IN]	.0100	6.0150	.0155
INNER WEB [IN]	.0040	.0800	.0155
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/09.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	7.65	29.51	1.85	5.15	7.95
BR PRES [KPSI]	16.01	1.16	3.25	12.14	15.82
MN PRES [KPSI]	15.89	1.17	3.24	12.06	15.71
BS PRES [KPSI]	15.67	1.17	3.21	11.91	15.48
MEAN TEMP [K]	2190.	1213.	2538.	2307.	2167.
TRAVEL [IN]	10.7	235.0	.2	2.4	12.3
VEL [FPS]	432.	920.	21.	135.	472.
ACCEL [G'S]	4136.	-116.	431.	2752.	4081.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.132	1.000	1.000
FR BRNT PROP 3	.951	1.000	.088	.481	1.000

800-CU-IN CHAM; 235-IN TRAVEL; 4/3 OF 16.0-KPSI ZONE-1 WT

GUN TYPE: DSWS 800	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 800.00 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 9.8
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M1, SP
WEIGHT [LB]	.188	.350	5.837
IMPETUS [FT-LB/LB]	346180.	180000.	305000.
FLAME TEMP [K]	3034.	1553.	2417.
ALPHA	.8650	1.0000	.7140
BETA	.000826	.001500	.001600
GAMMA	1.235	1.250	1.259
COVOL [CU IN/LB]	29.680	30.000	30.570
DENS [LB/CU IN]	.06033	.03400	.05670
GRAIN TYPE	1-PERF	1-PERF	1-PERF
GRAIN LEN [IN]	.0040	15.0000	.2093
GRAIN DIAM [IN]	.0180	6.1750	.0465
PERF DIAM [IN]	.0100	6.0150	.0155
INNER WEB [IN]	.0040	.0800	.0155
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/09.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	6.55	24.22	1.60	4.25	6.65
BR PRES [KPSI]	21.66	1.51	3.95	15.47	21.47
MN PRES [KPSI]	21.45	1.51	3.92	15.33	21.27
BS PRES [KPSI]	21.04	1.52	3.87	15.07	20.86
MEAN TEMP [K]	2185.	1204.	2521.	2317.	2174.
TRAVEL [IN]	11.9	235.0	.2	2.5	12.5
VEL [FPS]	545.	1170.	24.	164.	564.
ACCEL [G'S]	5823.	-12.	689.	3743.	5768.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.131	1.000	1.000
FR BRNT PROP 3	.984	1.000	.084	.455	1.000

874-CU-IN CHAM; 1/4 OF 47.5-KPSI TOP-ZONE WT; SIZE CHAM FOR ZONE 2

GUN TYPE: DSWS 1400	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 873.81 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 9.0
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	6.583
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 4 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	9.05	29.89	2.10	6.25	23.05
BR PRES [KPSI]	12.38	2.24	2.54	9.84	3.96
MN PRES [KPSI]	12.25	2.23	2.53	9.76	3.94
BS PRES [KPSI]	12.00	2.21	2.51	9.59	3.88
MEAN TEMP [K]	2261.	1517.	2578.	2290.	1717.
TRAVEL [IN]	8.9	235.0	.2	2.0	143.0
VEL [FPS]	332.	1158.	17.	93.	1069.
ACCEL [G'S]	2984.	208.	210.	1972.	642.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.124	1.000	1.000
FR BRNT PROP 3	.398	1.000	.035	.207	1.000

1150-CU-IN CHAM; 47.5-KPSI TOP ZONE FROM 1400-CU-IN CHAM

GUN TYPE: M198	BORE LENGTH: 200.0 IN
CHAMBER VOLUME: 1150.00 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 6.2
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	26.331
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	-------	-------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	4.65	11.73	1.25	2.70	7.35
BR PRES [KPSI]	60.65	10.13	6.91	29.80	36.34
MN PRES [KPSI]	58.22	9.77	6.68	28.70	34.92
BS PRES [KPSI]	53.36	9.07	6.22	26.51	32.07
MEAN TEMP [K]	2309.	1485.	2570.	2443.	1950.
TRAVEL [IN]	14.5	200.0	.2	1.7	66.8
VEL [FPS]	991.	2789.	29.	195.	2132.
ACCEL [G'S]	15971.	2318.	1504.	7220.	9348.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.146	1.000	1.000
FR BRNT PROP 3	.544	1.000	.034	.166	1.000

1150-CU-IN CHAM; 3/4 OF 47.5-KPSI TOP-ZONE WT FROM 1400-CU-IN CHAM

GUN TYPE: M198	BORE LENGTH: 200.0 IN
CHAMBER VOLUME: 1150.00 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 6.2
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	19.748
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	6.15	14.96	1.55	3.70	10.40
BR PRES [KPSI]	36.06	7.81	4.60	20.75	20.35
MN PRES [KPSI]	34.96	7.61	4.50	20.18	19.76
BS PRES [KPSI]	32.77	7.20	4.30	19.03	18.57
MEAN TEMP [K]	2313.	1575.	2577.	2422.	1937.
TRAVEL [IN]	15.6	200.0	.2	2.2	85.5
VEL [FPS]	799.	2275.	24.	177.	1833.
ACCEL [G'S]	9509.	1749.	869.	4960.	5147.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.131	1.000	1.000
FR BRNT PROP 3	.519	1.000	.033	.182	1.000

1150-CU-IN CHAM; 1/2 OF 47.5-KPSI TOP-ZONE WT FROM 1400-CU-IN CHAM

GUN TYPE: M198
CHAMBER VOLUME: 1150.00 CU IN
GROOVE DIAMETER: 6.200 IN
GROOVE/LAND RATIO: 1.660
TWIST: ONE TURN IN 20.0 CALIBERS
PRESSURE GRADIENT: LAGRANGIAN
PROJECTILE: M549A1

BORE LENGTH: 200.0 IN
TIME STEP: .100 MS
LAND DIAMETER: 6.100 IN
BORE AREA: 29.828 SQ IN
EXPANSION RATIO: 6.2
EROSIVE COEFF: 0.0000000
PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	13.166
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	8.35	20.08	2.05	5.20	15.25
BR PRES [KPSI]	20.69	5.28	3.14	13.43	10.66
MN PRES [KPSI]	20.27	5.20	3.11	13.20	10.46
BS PRES [KPSI]	19.44	5.03	3.04	12.73	10.06
MEAN TEMP [K]	2309.	1632.	2577.	2386.	1903.
TRAVEL [IN]	15.1	200.0	.2	2.2	105.7
VEL [FPS]	592.	1736.	19.	132.	1479.
ACCEL [G'S]	5326.	1079.	399.	2987.	2515.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.129	1.000	1.000
FR BRNT PROP 3	.492	1.000	.035	.196	1.000

1150-CU-IN CHAM; 1/4 OF 47.5-KPSI TOP-ZONE WT FROM 1400-CU-IN CHAM

GUN TYPE: M198
CHAMBER VOLUME: 1150.00 CU IN
GROOVE DIAMETER: 6.200 IN
GROOVE/LAND RATIO: 1.660
TWIST: ONE TURN IN 20.0 CALIBERS
PRESSURE GRADIENT: LAGRANGIAN
PROJECTILE: M549A1

BORE LENGTH: 200.0 IN
TIME STEP: .100 MS
LAND DIAMETER: 6.100 IN
BORE AREA: 29.828 SQ IN
EXPANSION RATIO: 6.2
EROSIVE COEFF: 0.0000000
PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	6.583
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.1710
SLOT WIDTH [IN]	-------	-------	.0100
PERF DIAM [IN]	.0100	6.0150	.0570
INNER WEB [IN]	.0040	.0800	.0570
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	12.45	31.24	2.75	8.20	24.55
BR PRES [KPSI]	10.88	2.66	1.87	7.80	4.78
MN PRES [KPSI]	10.78	2.64	1.87	7.75	4.75
BS PRES [KPSI]	10.57	2.61	1.87	7.66	4.67
MEAN TEMP [K]	2296.	1616.	2586.	2317.	1838.
TRAVEL [IN]	10.3	200.0	.2	1.3	115.3
VEL [FPS]	335.	1104.	11.	50.	988.
ACCEL [G'S]	2535.	333.	32.	1064.	847.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.120	1.000	1.000
FR BRNT PROP 3	.475	1.000	.036	.221	1.000

1400-CU-IN CHAM; 40.0-KPSI TOP ZONE

GUN TYPE: DSWS 1400	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 1400.00 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 6.0
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	29.750
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	6.55	15.71	1.65	3.80	13.95
BR PRES [KPSI]	40.02	10.78	4.64	21.01	14.73
MN PRES [KPSI]	38.28	10.35	4.50	20.19	14.13
BS PRES [KPSI]	34.81	9.51	4.22	18.55	12.93
MEAN TEMP [K]	2309.	1662.	2575.	2436.	1778.
TRAVEL [IN]	18.4	235.0	.2	2.1	180.9
VEL [FPS]	899.	2636.	24.	170.	2468.
ACCEL [G'S]	10152.	2463.	831.	4802.	3510.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.135	1.000	1.000
FR BRNT PROP 3	.428	1.000	.025	.134	1.000

1400-CU-IN CHAM; 3/4 OF 40.0-KPSI TOP-ZONE WT

GUN TYPE: DSWS 1400
CHAMBER VOLUME: 1400.00 CU IN
GROOVE DIAMETER: 6.200 IN
GROOVE/LAND RATIO: 1.660
TWIST: ONE TURN IN 20.0 CALIBERS
PRESSURE GRADIENT: LAGRANGIAN
PROJECTILE: M549A1

BORE LENGTH: 235.0 IN
TIME STEP: .100 MS
LAND DIAMETER: 6.100 IN
BORE AREA: 29.828 SQ IN
EXPANSION RATIO: 6.0
EROSIVE COEFF: 0.0000000
PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	22.313
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	8.45	19.82	2.05	5.05	19.35
BR PRES [KPSI]	25.48	8.15	3.27	14.85	8.67
MN PRES [KPSI]	24.65	7.92	3.21	14.43	8.41
BS PRES [KPSI]	22.98	7.44	3.10	13.59	7.90
MEAN TEMP [K]	2311.	1730.	2579.	2414.	1754.
TRAVEL [IN]	18.6	235.0	.2	2.2	223.0
VEL [FPS]	724.	2143.	19.	139.	2114.
ACCEL [G'S]	6442.	1828.	444.	3257.	1973.
FR BRNT PROP 1	1.000	1.000	1.000	1.000	1.000
FR BRNT PROP 2	1.000	1.000	.128	1.000	1.000
FR BRNT PROP 3	.411	1.000	.025	.143	1.000

1400-CU-IN CHAM; 1/2 OF 40.0-KPSI TOP-ZONE WT

GUN TYPE: DSWS 1400
CHAMBER VOLUME: 1400.00 CU IN
GROOVE DIAMETER: 6.200 IN
GROOVE/LAND RATIO: 1.660
TWIST: ONE TURN IN 20.0 CALIBERS
PRESSURE GRADIENT: LAGRANGIAN
PROJECTILE: M549A1

BORE LENGTH: 235.0 IN
TIME STEP: .100 MS
LAND DIAMETER: 6.100 IN
BORE AREA: 29.828 SQ IN
EXPANSION RATIO: 6.0
EROSIVE COEFF: 0.0000000
PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	14.875
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	11.25	26.38	2.60	7.00	-----
BR PRES [KPSI]	15.79	5.17	2.23	10.07	-----
MN PRES [KPSI]	15.45	5.08	2.21	9.90	-----
BS PRES [KPSI]	14.77	4.89	2.19	9.56	-----
MEAN TEMP [K]	2312.	1737.	2584.	2382.	-----
TRAVEL [IN]	16.3	235.0	.2	1.8	-----
VEL [FPS]	527.	1631.	13.	86.	-----
ACCEL [G'S]	3863.	1040.	145.	1919.	-----
FR BRNT PROP 1	1.000	1.000	1.000	1.000	-----
FR BRNT PROP 2	1.000	1.000	.122	1.000	-----
FR BRNT PROP 3	.396	.969	.026	.156	-----

1400-CU-IN CHAM; 1/4 OF 40.0-KPSI TOP-ZONE WT FROM 1400-CU-IN CHAM; ATTEMPT TO SIZE CHAM FOR ZONE 2

GUN TYPE: DSWS 1400
CHAMBER VOLUME: 1400.00 CU IN
GROOVE DIAMETER: 6.200 IN
GROOVE/LAND RATIO: 1.660
TWIST: ONE TURN IN 20.0 CALIBERS
PRESSURE GRADIENT: LAGRANGIAN
PROJECTILE: M549A1

BORE LENGTH: 235.0 IN
TIME STEP: .100 MS
LAND DIAMETER: 6.100 IN
BORE AREA: 29.828 SQ IN
EXPANSION RATIO: 6.0
EROSIVE COEFF: 0.0000000
PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	7.438
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 1 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	16.75	41.23	3.45	10.75	-----
BR PRES [KPSI]	8.68	2.53	1.40	5.85	-----
MN PRES [KPSI]	8.59	2.51	1.40	5.84	-----
BS PRES [KPSI]	8.42	2.49	1.41	5.81	-----
MEAN TEMP [K]	2300.	1691.	2593.	2302.	-----
TRAVEL [IN]	10.5	235.0	.2	.9	-----
VEL [FPS]	289.	1016.	6.	29.	-----
ACCEL [G'S]	1860.	295.	-45.	313.	-----
FR BRNT PROP 1	1.000	1.000	1.000	1.000	-----
FR BRNT PROP 2	1.000	1.000	.116	1.000	-----
FR BRNT PROP 3	.393	.962	.027	.173	-----

1202-CU-IN CHAM; 1/4 OF 40.0-KPSI TOP-ZONE WT FROM 1400-CU-IN CHAM; ATTEMPT TO SIZE CHAM FOR ZONE 2

GUN TYPE: DSWS 1400	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 1202.31 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 6.8
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	7.438
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	-------	-------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 2   82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	14.05	38.04	3.00	9.25	------
BR PRES [KPSI]	9.44	2.47	1.66	6.76	------
MN PRES [KPSI]	9.34	2.45	1.66	6.74	------
BS PRES [KPSI]	9.14	2.43	1.66	6.68	------
MEAN TEMP [K]	2284.	1657.	2587.	2294.	------
TRAVEL [IN]	9.4	235.0	.2	1.0	------
VEL [FPS]	290.	1030.	9.	39.	------
ACCEL [G'S]	2088.	277.	-21.	573.	------
FR BRNT PROP 1	1.000	1.000	1.000	1.000	------
FR BRNT PROP 2	1.000	1.000	.120	1.000	------
FR BRNT PROP 3	.358	.932	.027	.167	------

601-CU-IN CHAM; 1/4 OF 40.0-KPSI TOP-ZONE WT FROM 1400-CU-IN CHAM; ATTEMPT TO SIZE CHAM FOR ZONE 2

GUN TYPE: DSWS 1400	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 601.15 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 12.7
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	7.438
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 3 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	5.85	28.51	1.45	4.50	-----
BR PRES [KPSI]	13.54	2.14	3.75	12.39	-----
MN PRES [KPSI]	13.39	2.13	3.72	12.26	-----
BS PRES [KPSI]	13.08	2.12	3.67	12.00	-----
MEAN TEMP [K]	2185.	1521.	2564.	2209.	-----
TRAVEL [IN]	5.9	235.0	.2	2.5	-----
VEL [FPS]	280.	1050.	24.	143.	-----
ACCEL [G'S]	3317.	179.	607.	2790.	-----
FR BRNT PROP 1	1.000	1.000	1.000	1.000	-----
FR BRNT PROP 2	1.000	1.000	.132	1.000	-----
FR BRNT PROP 3	.218	.804	.024	.142	-----

301-CU-IN CHAM; 1/4 OF 40.0-KPSI TOP-ZONE WT FROM 1400-CU-IN CHAM; ATTEMPT TO SIZE CHAM FOR ZONE 2

GUN TYPE: DSWS 1400
CHAMBER VOLUME: 300.58 CU IN
GROOVE DIAMETER: 6.200 IN
GROOVE/LAND RATIO: 1.660
TWIST: ONE TURN IN 20.0 CALIBERS
PRESSURE GRADIENT: LAGRANGIAN
PROJECTILE: M549A1

BORE LENGTH: 235.0 IN
TIME STEP: .100 MS
LAND DIAMETER: 6.100 IN
BORE AREA: 29.828 SQ IN
EXPANSION RATIO: 24.3
EROSIVE COEFF: 0.0000000
PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	7.438
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	--------	--------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

RUN: 4 82/12/08.

CONDITIONS AT:	MAX PR	MUZZLE	PROP 1 BURNT	PROP 2 BURNT	PROP 3 BURNT
TIME [MS]	1.85	22.47	.60	1.75	------
BR PRES [KPSI]	28.51	1.76	11.49	28.45	------
MN PRES [KPSI]	28.16	1.76	11.35	28.10	------
BS PRES [KPSI]	27.45	1.75	11.06	27.40	------
MEAN TEMP [K]	2094.	1354.	2506.	2101.	------
TRAVEL [IN]	2.1	235.0	.1	1.8	------
VEL [FPS]	253.	1089.	40.	229.	------
ACCEL [G'S]	7595.	64.	3093.	7513.	------
FR BRNT PROP 1	1.000	1.000	1.000	1.000	------
FR BRNT PROP 2	1.000	1.000	.167	1.000	------
FR BRNT PROP 3	.126	.703	.023	.116	------

150-CU-IN CHAM; 1/4 OF 40.0-KPSI TOP ZONE FROM 1400-CU-IN CHAM; ATTEMPT TO SIZE CHAM FOR ZONE 2

GUN TYPE: DSWS 1400	BORE LENGTH: 235.0 IN
CHAMBER VOLUME: 150.29 CU IN	TIME STEP: .100 MS
GROOVE DIAMETER: 6.200 IN	LAND DIAMETER: 6.100 IN
GROOVE/LAND RATIO: 1.660	BORE AREA: 29.828 SQ IN
TWIST: ONE TURN IN 20.0 CALIBERS	EXPANSION RATIO: 47.6
PRESSURE GRADIENT: LAGRANGIAN	EROSIVE COEFF: 0.0000000
PROJECTILE: M549A1	PROJ WT: 95.000 LB

ENGRAVING & FRICTIONAL RESISTANCE [KPSI] VS. TRAVEL [IN]:

TRAVEL:	0.00	.40	1.00	1.55	2.05	4.50	200.00
RESISTANCE:	.25	3.35	4.95	3.63	3.25	2.50	1.50

PROPELLANT	CBI	COMB CASE	M31,SSP
WEIGHT [LB]	.188	.700	7.438
IMPETUS [FT-LB/LB]	346180.	180000.	328500.
FLAME TEMP [K]	3034.	1553.	2587.
ALPHA	.8650	1.0000	.7520
BETA	.000826	.001500	.001602
GAMMA	1.235	1.250	1.251
COVOL [CU IN/LB]	29.680	30.000	30.580
DENS [LB/CU IN]	.06033	.03400	.05930
GRAIN TYPE	1-PERF	1-PERF	SLOTTED
GRAIN LEN [IN]	.0040	30.0760	10.0000
GRAIN DIAM [IN]	.0180	6.1750	.2355
SLOT WIDTH [IN]	-------	-------	.0100
PERF DIAM [IN]	.0100	6.0150	.0785
INNER WEB [IN]	.0040	.0800	.0785
IGNITION CODE	0	0	0
THRESHOLD VALUE	0.00000	0.00000	0.00000

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2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

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3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) ______________________

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4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

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5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) ______________________

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